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35V

REDUCTION OF ENERGY LOSS
IN A TRAIN REPAIR SHOP
(ABBREVIATED TO LARGE DOOR LOSSES)

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580 Booth Street
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K1A 0E4

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Nomenclature and Abbreviations

N	=	the fraction of internal air exchanged (No. of airchanges)
g	=	gravitational acceleration
ℓ	=	a reference length dimension
ρ_i	=	initial internal air density
ρ_o	=	outside air density
t	=	time
T	=	temperature
C_p	=	specific heat for air at constant pressure
Vol	=	internal volume of the spot repair shop
Q	=	the air flow rate through the doors
C	=	the overall normal heat loss coefficient
H	=	input energy from heaters and lights
°C	=	degrees Celsius
°F	=	degrees Fahrenheit
m	=	meters
mm	=	millimeters
ft	=	feet
mi	=	miles
L/s	=	litres per second
CFM	=	cubic feet per minute
kW	=	kilowatts
Btu/hr	=	British thermal units per hour
kWh	=	kilowatt hours
Btu	=	British thermal units
MCF	=	thousands of cubic feet

Note: Some cost and performance data which was obtained from specification plates on equipment or from manufacturers literature was given in imperial units and has therefore been included in these units in this report.

1.0 EXECUTIVE SUMMARY

In this study the heat losses from a railway spot repair shop, located near Toronto, Ontario, were investigated with a view to reducing energy consumption. Typically, forty to fifty rail cars pass through the shop each day on three parallel tracks and the six roll-up doors at the south and north ends are frequently open. Some rail cars protrude through the doors during repairs, preventing them from being closed for half an hour or more. The open doors alow the warm internal air to escape and, when doors are open simultaneously at the south and north ends, cold winds can blow right through the shop. The spot repair shop is similar to a number of others in Canada. Working conditions for the shop personnel are not expected to be as for indoors, since historically many spot repairs have been done outdoors, but an improved working environment during the winter months was considered a desirable additional objective.

The prime focus of this study was therefore the reduction of heat loss through the doors. Proper consideration was given to the effect of any modifications on the safety of shop personnel.

Scale models were used to investigate the heat losses through the doors. Wind tunnel tests, water flume tests and other experiments were performed on the models in order to determine the effects of wind, the rate of escape through the doors of the warm internal air due to its buoyancy, and the influence of modifications such as exterior wind breaks or strip curtains in the doorways. Data from the model tests were then incorporated into a computer model of the shop, including its heating and ventilation systems, the rail cars, the doors and the exterior winds and temperatures. This computer model could simulate up to 10 years of the shop's energy usage and interior temperature on a minute by minute basis and was used to evaluate the effectiveness of various methods of reducing energy losses.

A negative finding of the study was that exterior wind breaks, although capable of reducing the wind speeds and wind chill through the doorways when doors are open at both ends of the shop simultaneously, would not be very effective as energy savers and would provide only minor improvements in the shop's internal temperatures. The primary reason is that the great majority of door openings involve doors at only one end at a time and exterior wind breaks are not particularly effective in this most common condition. The use of air curtains was considered but the excessive cost ruled out a blanket application of these devices on all six doorways.

The most cost effective method of reducing energy losses without adversely affecting the interior temperatures was found to be the installation of strip curtains at the door combined with modifications and resetting of the thermostats controlling the infrared heating system. For safety, and at the expense of some energy losses, a 2.1 m (6.9 ft) gap should be left between the bottom of the curtains and the floor, thereby ensuring good visibility through the door and preventing shop personnel from being hit by a swinging curtain after a car passes through. It is important to note here that the energy savings provided by the strip curtains alone were not large, on the order of 5%, their main achievement being an improvement in the interior temperatures. The energy savings would have been increased were it not for the fact that higher interior temperatures inevitably lead to greater losses by conduction through the shop's walls and roof. Much of the energy savings came from isolating infrared heater thermostats mounted on walls from the walls themselves, thereby ensuring the thermostats read the true internal temperature rather than the wall temperature which would be close to that outside at many of the thermostat locations. The existing thermostat wall mountings cause some of the heaters to be on nearly continuously whenever outdoor temperatures fall below the thermostat setting. Further energy savings would be obtained by setting the thermostats to stipulate 13°C (55°F) rather than the current value of 16.7°C (62°F). Were it not for the strip curtains these changes to the thermostats would cause a degradation of the working environment but the combination of these changes and the strip

curtains enables substantial energy savings (40%) to be obtained without adversely affecting the working environment. In fact, the working environment was found to be improved.

The 2.1 m gap beneath the strip curtains described above would result in there still being areas near to open doors where low temperatures would exist during winter. The size of these areas would be smaller than without strip curtains but this would not be perceived by those working near the door. For this reason, an evaluation was made of the benefits of heated air curtains blowing horizontally across the 2.1 m gaps of the three south doors. The north doors are not opened for as long as the south doors and it is less probable that personnel will be required to work close to them for long periods. The air curtains improved the comfort significantly but from the strict point of view of energy savings would not provide a return on investment approaching the 35% to 40% range desired. The reasons are the high initial cost of equipment and installation and the energy consumption of the heated air curtains themselves. Unheated air curtains were considered undesirable on the basis that they would not improve the comfort near the doors.

The payback period for the package of measures comprising the strip curtains, adjustments and modifications of the thermostats, and refinements to the ventilation system was calculated with and without heated air curtains. The following is a summary of the costs and payback times of each of these packages:

	System Without Air Curtains	System With Heated Air Curtains
Initial Investment	$14,600	$46,400
1983 Net Annual Operating Saving	$15,745	$10,375
Simple Payback	0.93 yrs.	4.5 yrs.
True Payback	1.1 yrs.	8.3 yrs.

Full details of the study's findings, some of which would be applicable to a degree in other shops, are contained in the body of the report.

2.0 INTRODUCTION

2.1 General

The background to the study is described in the Executive Summary of this report, Section 1. At the outset the most obvious cause of energy losses was perceived to be the "wind tunnel" effect through the shop and the study's purpose was to reduce energy losses resulting from it. The owner listed the objectives as:-

(a) Develop conceptual design and cost estimates for interior modifications or exterior appurtenances to the building, relative to the study purpose.

(b) Assess the operational features of the spot repair section relative to varying, prevailing wind conditions and determine changes to the operation within the limits of practicality and safety.

2.2 Shop Operation

The car repair shop consists of two shops in the same building. Figure 2 shows photographs of the scale models used in the study and Figure 3 gives an orientation plan of the shop. The larger shop on the west side of the building is the main shop where major repairs to the cars are performed. The smaller shop on the east side of the building is the spot repair shop which was the subject of this study. These shops are separated by offices but there is a passageway for lift trucks and personnel between the two shops. Adjacent to but with no internal connection to the main shop on the west side is the mechanical reefer shop. This was omitted from the scale models due to its distance from the spot repair shop. This would cause it to be of little significance to the wind flows at the spot repair shop.

The repairs done in the spot repair shop are usually less complex than in the main shop and therefore the throughput is quite high at an average of 46

cars per day. The spot repair facility operates around the clock on three shifts. For these reasons, the doors are opened often and at all times of the day. The robot car puller system that moves the cars into and out of the shop is interlocked with the opening of the doors such that the car cannot begin moving until the door has been opened. After the car has been positioned, the doors are closed by manual controls operated by the shop personnel. The cars are moved through the shop from the south to the north end. Jacks, for working on wheels, are permanently incorporated into the shop floor at the south end of the building. In addition to the normal opening and closing of the doors, there is the possibility that a car, which is too long to be serviced on a jack completely inside the shop, will protrude from one of the three south doors. Of the total number of cars in use, 21.5% fall into this 'long' category and it was assumed that one half of these cars must protrude from the doorway to have repairs made. The justification for this assumption is that the car need only protrude when the first wheel truck is to be repaired or replaced and the car must be raised on jacks.

In order to move a car out of a north door, the door is typically open for about two minutes after which the door may be closed since the car being moved out has cleared the doorway. Moving cars into the shop at the south end however usually takes somewhat longer. The cars, which are waiting to be repaired, are usually in one of four positions on the track, each being a different distance from the shop door. The robot car puller is coupled to the door mechanism such that the car begins its travel toward the shop only after the door has opened. For this reason the south door open times vary depending on the original position of the car being moved. The average time that a south door is open is about five minutes. All doors on the three tracks are operated independently and therefore multiple door openings are random in nature.

3.0 HEAT LOSS INVESTIGATION

Initial consideration of the causes of heat loss from the spot repair shop made it apparent that the following factors must be taken into account.

i) Normal Energy Loss

These losses are not related to the flow of air into or out of a doorway when the door is open. They include conduction losses through walls, roofs and floors, energy lost to ventilation and make-up air, infiltration through door and window seals as well as the heat absorbed by the rail cars themselves when they are in the shop. These losses were evaluated for the entire shop by using standard thermal conductance values tabulated for each type of material and construction of each major portion of the structure. The losses were calculated based on 111.5 m^2 of single glazing, 2 189 m^2 of walls of two different constructions, 7 511 m^2 of on grade floors, 120 m for perimeter losses, 7 511 m^2 of roof and 548 m^2 of doors. The total infiltration through closed door and window seals was estimated at 11 800 L/s (litres per second) using standard tabulated values obtained for the specific types of doors and windows installed in the building. The total volume flow of air for mechanical exhaust and make-up air was 21 200 L/s as was obtained from the equipment specifications.

ii) Frequency and Duration of Door Openings

The desire to obtain quantitative information on the total energy losses due to wind flows through the building made it necessary to incorporate the normal opening and closing of the doors with regard to frequency and duration. This information was obtained by means of a survey of door opening and closing times taken during the period of December 7 through 18, 1982. Table 1 gives an example of the survey

information taken for one of the tracks on December 8th. The overall results of these surveys were combined to provide an estimate of the probabilities of various combinations of door openings. Table 2 gives the probabilities of these combinations occurring within any given hour and the assumed durations which were used for the overall heat loss determination.

iii) Wind Speed, Direction and Temperature

The heat lost to wind flows through a building is a function of the wind's speed, direction and temperature when doors are open at each end of the building simultaneously. Magnetic tapes containing the mean hourly values of the wind speed, direction and temperature recorded at Toronto International Airport, 30 km (18 mi) from the shop, were obtained from the Atmospheric Environment Service. The records covered the period from 1953 through 1981.

iv) Wind Flows Through the Building

The amount of air flow through the building caused by wind depends on the ambient wind speed and direction as well as which doors are open at the time being considered. A 1:200 scale model of the building, Figure 2, and the local surrounding terrain was constructed out of clear plexiglass in order to allow viewing the wind flows within the building in addition to those outside the building. This model was placed in the consultant's water flume in which water passing over the model simulates local wind patterns. Visualization of these flows was accomplished by introducing a dye stream into the water at the point of interest. The model could be rotated in order to produce the effect of winds approaching the site from any direction.

Initially the existing wind flows through the shop were observed with different doors open and then the effectiveness of various types of

exterior wind breaks or deflectors in blocking the wind flows was assessed.

The same 1:200 scale model was then tested in the boundary layer wind tunnel at the consultant's laboratory. This facility provided a simulation of the natural wind's velocity profile and turbulence levels at the site. Wind velocity sensors in the model's doorways measured the amount of air entering and exiting the shop due to wind effects for 16 wind azimuths in 22.5 degree increments.

The measurements were taken for the existing condition, to be used as a baseline for comparison, and with each of the more promising wind breaks identified in th flow visualization tests. The results of these tests yielded doorway velocities, as a fraction of the ambient wind speed, versus wind direction for the various possible open door combinations, with and without the wind breaks present.

v) Buoyancy Losses

These losses are due to the escape of warm buoyant air out of the upper portion of the doorway when the door is open. This warm air is replaced by cold outside air which enters at the lower portion of the doorway. To personnel standing near the doorway, this effect is perceived as a wind flow into the building.

Estimates of the amount of air exchanged due to the opening of a door were obtained by constructing a 1:50 scale model of the spot repair scale model of the spot repair shop also shown in Figure 2. A single door which could be opened and closed was incorporated into the model. The effect of wind on the losses due to buoyancy was assumed to be neutral on average and was not included in this portion of the testing in order to simplify the test procedure.

With the door closed, the model was filled with a metered mixture of air and helium of known density and therefore known buoyancy. A small quantity of carbon monoxide gas, the concentration of which was monitored by a carbon monoxide meter, was introduced into the model and was well mixed through the use of a mechanical mixing device incorporated into the model. The door of the model was then opened for a given period of time to allow some of the buoyant internal gas to escape and to be replaced by outside air as would occur in full scale. After the door was closed, the internal gas was thoroughly mixed to again provide a uniform internal gas mixture. Since this mixture was diluted by the amount of air changed, the final reading of the internal carbon monoxide concentration, compared with the concentration prior to opening the door yielded the amount of air exchanged.

This same procedure, repeated many times varying the initial internal gas density and the door open duration, provided data which was translated to full scale by means of a dimensional analysis. This could then be used to predict the heat lost due to a door being opened for a given time on the actual spot repair shop. The dimensional analysis indicated that the fraction of the internal air exchanged could be expressed as follows:

$$N = f\left(\frac{g}{\ell}\frac{P_o - \bar{P}_i}{P_o}\, t\right)$$

where
- N = the fraction of internal air changed
- g = gravitational acceleration
- ℓ = a reference length dimension
- P_i = the initial, internal air density
- P_o = the density of the outside air
- t = time

The function f was determined and is given later in Section 5.2.

4.0 COMPUTER SIMULATION

4.1 General

To calculate the combined effects of all the heat loss factors discussed in Section 3.2, a computer model of the heat balance of the shop was developed. It was capable of accounting for exterior wind and temperature conditions, the random nature of openings and closings of doors, the operation of the thermostat controlled heaters, the effects of wind breaks or strip curtains, and the heat sink effect of the cold rail cars entering the shop. It provided a minute by minute history of the heat flows and internal temperatures. The influence of internal stratification was not included because it was considered to be generally a second order effect that would have further complicated the analysis. The infrared heaters would be expected to reduce stratification as compared with other heating systems since they radiate heat down to floor level. The data from the wind tunnel tests and buoyancy loss tests were incorporated into the program.

4.2 Theory of Operation

The program set the wind direction and speed and outside temperature to the values in the recorded weather data from the Atmospheric Environment Service for the hour being simulated.

A random number generator produced the sequence of events of door openings which occurred during the hour based upon their probability of occurrence. This probability was obtained from the results of the operational survey discussed in Section 3.2. The effects of flows through the interconnecting passageway between the two shops, due to doors open in each shop simultaneously, were not accounted for in this simulation because of their small probability of occurrence as compared to that for the spot repair shop alone. This was done in order to simplify the simulation. The internal

temperature was calculated on a minute by minute basis over the hour and included the effects of open doors, general heat loss, thermostat positioning and setting and total energy input from heaters and lighting. The basic assumption for the energy loss due to airflows into and out of the building when doors were open at both ends was one of perfect internal mixing. The assumption of perfect mixing was an approximation which was necessary in order to simplify the heat loss estimation. It would be expected to result in slight underestimates of energy savings. The heat balance for the spot repair shop which was used is expressed in the following equation.

$$U_1 - U_2 = (H/a)(1-e^{at}) + U_{io} - U_e)e^{-at}$$

where $U_1 = Vol/Cp\ T_i$

$U_e = Vol/Cp\ T_e$

$U_{io} = Vol/Cp\ T_{io}$

$$a = \frac{Q}{Vol} + \frac{C}{Cp\ Vol}$$

$U_1 - U_2$ = the change in total internal energy of the air from time 1 to time 2

T_i = the instantaneous internal temperature

T_e = the external temperature

T_{io} = the initial internal temperature

C_p = the specific heat for air at constant pressure

ρ = the average air density

Vol = the internal volume of the shop

Q = the air flow rate through the doors

C = the overall normal heat loss coefficient

t = time measured from the instant of door opening

H = energy input from heaters and lights

This minute by minute simulation could be continued for any desired length of time up to 10 years.

4.3 Outputs

The computer simulation predicted the temperature variation with time taking into account the random occurrences of door openings. Examples of

these temperature fluctuations are given in Figures 4(a) to (d). These figures represent the simulated temperature for four consecutive hours on January 2, 1971, for the shop in its existing condition. Figure 4(a) is representative of an hour in which a long car was being repaired and was protruding from one of the open south doors for the first 30 minutes. At approximately the 12 minute mark, a north door was also opened resulting in a sudden reduction of temperature due to additional wind and buoyancy losses. After this north door reclosed at the 14 minute mark, the temperature increased somewhat. At the 30 minute mark, all doors were closed and remained so for the rest of the hour which allowed the heaters to bring the temperature back to the thermostat set point of 16.7°C (62°F). Figure 4(b) illustrates an hour in which two door opening occurences were simulated. The first being the opening of a single south door for 5 minutes and the second a single north doors for 2 minutes. The hour shown in Figure 4(c) had only one occurence of doors opening. This was with one door at each end open simultaneously. The combination of wind flows through the building and the buoyancy losses results in the rapid decrease of temperature during the first 2 minutes. Five occurrences were simulated in the fourth hour, Figure 4(d). In the order they were simulated, these were two doors on one end open, two doors on one end and one on the other, one north door, one south door, and one door on each end. From these results, the random nature of the door simulation is apparent.

To obtain the total energy consumption as well as an indicator of internal comfort level for personnel, the simulation output gave weekly breakdowns of average internal temperature, the number of hours below 0°C, the number of hours below 6°C and the total number of hours that the heaters were on. Totals of the number of heater hours and the hours below 0°C and 6°C were also outputted for the entire simulation interval. From this, yearly average values could be obtained. The 0°C (32°F) level was chosen since it was felt that this temperature was an appropriate reference temperature below which the conditions could be classified as uncomfortable for shop personnel. The 6°C (43°F) level was chosen because it is approximately midway between the 0°C level and the shop design temperature of 13°C (55°F).

4.4 Effects of Shop Modifications

Through the alteration, based on model tests, of the appropriate input quantities and heat loss calculations, the overall effect of modifications to the shop on the energy consumption and comfort level could be readily assessed.

5.0 DISCUSSION OF RESULTS

5.1 Reduction of Wind Flows Through Shop

The initial flow visualization work done in the water flume indicated that the major wind induced airflow through the building is caused by winds from the north through northwest and east through south. From the inspection of the wind rose overlay to Figure 3 which illustrates both the frequency and speed of the winds during the winter months for Toronto, it can be seen that only the north through northwest winds would be of major concern as the winds from the east through south are relatively infrequent. For this reason, wind flow modifications which concentrated on reducing the north wind effects were tested. Many roof and ground mounted wind deflectors were tried, with only partial success.

One solution which gave good results at a reasonable cost was a straight 6 m high, 35 m long wind barrier mounted across tracks 12, 13 and 14, 25 m away from the north wall of the spot repair shop. This is illustrated in Figure 5. Note in this figure that the openings which allow the rail car to pass through are blocked down to 2.1 m from the ground with strip curtains. These curtains allow the cars to pass through, but effectively block the wind flows. Another solution tried was to place the same strip curtains in the shop doorways themselves on both ends of the spot repair shop, although this still allowed wind flows beneath the curtains to occur.

Testing the existing conditions and the above-mentioned remedial measures yielded the results given in Figure 6. The plot given in the figure gives the wind velocity ratio which is the fraction of the oncoming wind speed that was measured in the doorways. The variation from doorway to doorway was sufficiently small that the results were combined to produce one velocity curve for all doorways.

The wind deflector wall can be seen to have reduced the wind flows for the north wind direction by 41% and had only minimal effect for the entire south half of the wind direction range.

The test with strip curtains in all six doorways extending down to 2.1 m from the floor, but without the wind deflector wall, produced essentially the same measured velocities as the existing case. This was due to the fact that the velocities were measured as a height of about 1 m from the floor at full scale and therefore indicated the wind speed beneath the curtains. The effective velocity ratios given in Figure 6 were obtained by factoring the measured wind speed by the ratio of the area beneath the curtains over the complete door area. This effective velocity ratio was used in order to simplify the input to the computer simulation and for illustrative comparison of the overall reduction of volume flow rate through the shop when the strip curtains were installed.

From these tests it can be seen that the strip curtains in the shop doorways provided a greater reduction in the total wind induced air flow through the building than the wind barrier did regardless of the wind direction. It should be noted that although the total air flow due to the wind was reduced with the curtain, the velocity in the doorway remained essentially unchanged and personnel in this area would probably be of the impression that no flow reduction was achieved. The size of the affected area near the door would, however, be reduced by the strip curtain.

The effect of the flows through the passageway between the two shops was not investigated. The main flows in the passage occur when doors are simultaneously open in the main shop and the spot repair shop. This happens infrequently. However, these flows would be restricted by the addition of strip curtains within the passageway and this would improve the comfort conditions for personnel in the main shop near the passageway. Also, reduction of the wind flows through the spot repair shop doors, by the addition of strip curtains, would automatically reduce the flows through the passage.

5.2 Buoyancy Loss Reduction

From the 1:50 scale model tests, it was found that the amount of air lost for a given door opening and a given time period could be expressed as a fraction of the total volume of the spot repair shop by the following equation (see Section 3.1, Item v):

$$N = .00862 \left(\sqrt{g \frac{Po - Pi}{\rho_o}}\, t\right)^{.65}$$

where
- N = fraction of internal volume lost (# airchanges)
- g = gravitational acceleration
- ℓ = with of doorway
- o = outside air density
- i = initial inside air density
- t = duration of door opening

The actual test data and the relation given above are contained in Figure 7.

A similar expression described the buoyancy losses when strip curtains covered the upper two-thirds of the doorway except that the air exchange rate was reduced in proportion to the door area left open.

5.3 Overall Average Energy Loss

The determination of overall average energy loss per year required the use of the computer simulation previously discussed in order to properly deal with all the variables involved. Initially the computer was allowed to simulate the 10 year period from 1971 to 1981 for the existing condition. The yearly average values were calculated. Comparing the 10 year average with each individual yearly average indicated that 1971 was a good approximation to the 'average year'. Thus, in the interests of conserving computational time in order to test the effect of many changes to the building, 1971 alone was used for all subsequent simulations.

Table 3 contains the results of the various simulated configurations. In the existing condition more than half of the thermostats are mounted on perimeter walls and columns. These then, do not sense the true internal air temperature but, due to the high thermal conductivity of the walls, most probably sense a temperaure close to that of outside ambient air. The remaining thermostats are not mounted on outside walls and therefore would function as intended, sensing the internal air temperature. This is the condition referred to as 'existing' in the thermostat mounting column of Table 3. In this same column, the label 'isolated' refers to all perimeter heaters having been rewired such that they are controlled by centrally located thermostats.

The design temperature specified by CN at the outset of this study was 13°C (55°F). It was found, however, that the present setting of the thermostats is 16.7°C (62°F). The simulated thermostat setting is shown in the second column of Table 3.

All results given in the table are yearly average values in hours and the percent reduction in energy is referenced to the existing condition. Cases 1 through 5 in this table represent the overall effect of the addition of remedial solutions without modifying the thermostats in any way.

The baseline for comparison is case 1 in which the heaters averaged 4 550 heating hours per year. This compared fairly well with the number of heating hours estimated from power consumption records in the existing shop conditions, thereby verifying the accuracy of the computer model. From a comfort standpoint, the temperature averaged 184 hours below 6°C and 41.3 hours below 0°C per year. The addition of the wind deflector of Figure 4 reduced the overall energy consumption only 0.1% to 4 544 heating hours but reduced the hours below 6°C and 0°C by approximately 7% as seen in case 2. Case 3 shows the effect of adding strip curtains to each of the six doorways. These curtains extend down to 2.1 m from the floor. The result is a 5% reduction in the heat requirement accompanied by a large improvement in the

comfort level as evidenced by the average of 34 and 1.2 h below 6°C and 0°C respectively. Cases 4 and 5 are of particular interest in determining the potential savings brought about by eliminating the wind effects and the buoyancy effects. These purely theoretical results are of interest because they quantify the potential for energy savings and improvement of comfort conditions brought about by the complete elimination of door open buoyancy losses and wind flows. It was felt at the outset that these would be of prime importance to the overall energy loss and it can be seen that the elimination of either of these effects produces relatively small energy savings but significant benefits in comfort level. The explanation of this is that any changes which reduce the heat loss from the doors cause the average internal temperature to increase; thus the improvement in comfort level. However, this increased temperature accelerates all other heat losses such as structural conduction, ventilation, etc., due to the larger internal to external temperature difference.

In the previous cases, some of the thermostats were measuring a temperature very close to the outside ambient temperature and therefore a good portion of the heaters remained on no matter what the internal temperature was, as long as the external temperature was below the set point. Isolating these thermostats from the outside wall, case 6, showed good improvement in the overall energy consumption and only a slight degradation in comfort level. Again, the addition of strip curtains, case 7, made a small additional improvement in energy consumption and a good improvement in overall comfort.

Cases 8 to 12 represent the combination of isolated perimeter thermostats and all thermostats set to 13°C which was the desired future design temperature. Case 8, shows large improvements in overall energy consumption at a penalty of some reduction in the overall comfort level. The addition of remedial measures, cases 9 and 10, shows a good improvement in comfort levels over the baseline and a small energy savings over case 8.

Case 11 shows the results with strip curtains on all six doors and vertically mounted unheated air curtains blowing horizontally on both sides of

the lower 2.1 m of each south door. This shows significant improvement in overall comfort level in the shop while providing a small improvement in the energy savings over the strip curtains alone. The comfort level near the doors would likely not be acceptable due to the draftiness of the unheated air curtains. Heated aircurtains would eliminate this draftiness but would increase energy consumption due to the additional heat requirement.

The maximum possible benefit achievement by door and thermostat modifications alone was estimated by simulating air locks which would simultaneously reduce buoyancy and wind losses to zero. This is shown in case 12 where a 51.8% reduction in energy consumption is evident and at no time would the temperature be below 6°C. This case, although theoretical, illustrates the magnitudes of the open door losses in the overall energy consumption and comfort level.

5.4 Financial Analysis of Measures to Reduce Heat Loss

As discussed in Section 5.3, various remedial measures incorporated into the spot repair shop produced benefits in two distinct areas. These were either an improvement in comfort level or a reduction in the overall heater usage and thus in energy consumption. The requirement of this study was to reduce the energy consumption without adversely affecting efficiency and safety. The working conditions for the shop personnel are not expected to be as for indoors, but an improved working environment was considered desirable also. For this reason, the financial analysis was performed for 'packages' of recommended modifications which benefit both energy consumption and the environment for shop personnel. The full details of these recommended packages are contained in Appendix A.

In addition to other minor changes detailed in Appendix A, the major alterations to the spot repair facility contained in these packages are as follows:

Package 1:

- set all space heating thermostats to 13°C
- rewire all perimeter heaters to be controlled by centrally located thermostats
- install strip curtains on all six track doors down to a level of 2.1 m above the floor

Package 2:

- same as package 1 but with unheated air curtains protecting the lower 2.1 m of the south doorways

Package 3:

- same as package 1 but steam heated air curtains protecting the lower 2.1 m of the south doorways.

Package 1 without air curtains provides substantial savings in energy and some improvement in comfort level. The initial cost for implementing this package is also quite low in comparison to the other two alternatives. The payback time for this package is only 1.1 years and energy savings on the order of 40% would result.

Significant energy savings can be obtained without the use of air curtains on the lower 2.1 m of the south doorways as stated above, but they were included in packages 2 and 3 mainly in the interest of improving the working environment near the doorways. The financial analysis of package 2 without heated air curtains gave a true payback time of 2.9 years and with heated air curtains, package 3, 8.3 years. The difference here is caused by the higher initial cost and decreased fuel savings due to the heating requirement. It should be noted that although all air curtains are mounted inside the shop, unheated air curtains may not be acceptable to employees near the doors since

they would create cool drafts, thus negating the purpose of installing them, which was to improve comfort. This uncomfortable condition would be due to the high velocity flow from the air curtains in addition to some mixing of the air jet with outside air.

The detailed description, performance, savings, implementation and financial analyses are contained in Appendix A.

6.0 RECOMMENDATIONS

6.1 Reduction of Heat Loss from Spot Repair Shop

It is recommended that the following list of items be implemented for the spot repair facility. This package of items will yield the highest energy savings as well as providing some improvement in comfort.

1) Install strip curtains on all six track doors down to a level of 2.1 m above the floor.

2) Rewire all perimeter infrared heaters to centrally located thermostats.

3) Set all thermostats to 13°C.

4) Repair and calibrate all thermostats controlling the infrared heaters.

5) Repair the controls for both air make-up units and calibrate the thermostats.

6) Ensure that the two manually controlled exhaust fans are switched off in winter.

The payback for the above package is only 1.1 years because its initial cost is low and the savings substantial. With this package comfort in the shop would be improved but not by a large factor. In the interest of improving comfort near the doors it is recommended that the following addition to the above package be considered.

Install heated air curtains blowing horizontally across the bottom 2.1 m of the three south track doors. Fans should be interlocked with the door controls to start when the door is opened. A timer should be wired into

the door closing limit such that the fan runs for one minute after closing. Fan operation should also be overidden with an outside thermostat so that they will not run when that temperature is above 13°C.

The payback for the above package including the heated air curtains is 8.3 years. A complete description of the above items including implementation and estimated cost is contained in Appendix A and are listed as packages numbered 1 and 3.

It is recommended that a radio frequency remote door opener control be installed on the lift truck door. The control unit would be operated by the lift truck operator in order to minimize the time that this door is left open. It is also recommended that consideration be given to the installation of strip curtains in the passageway between the spot repair shop and the main shop. It is felt that this addition would reduce any air flows through this area and therefore improve the comfort conditions in the main shop near this passageway.

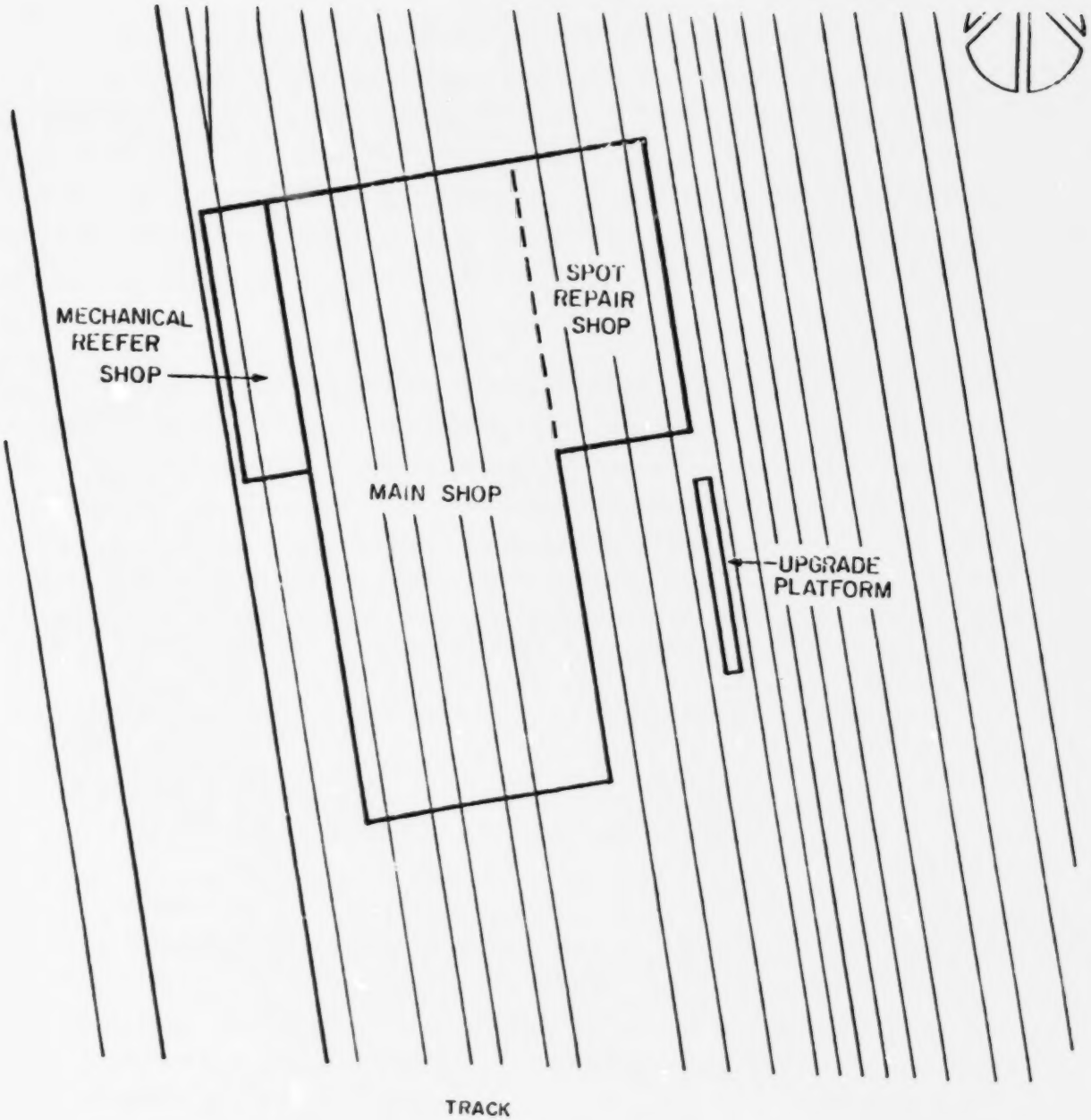
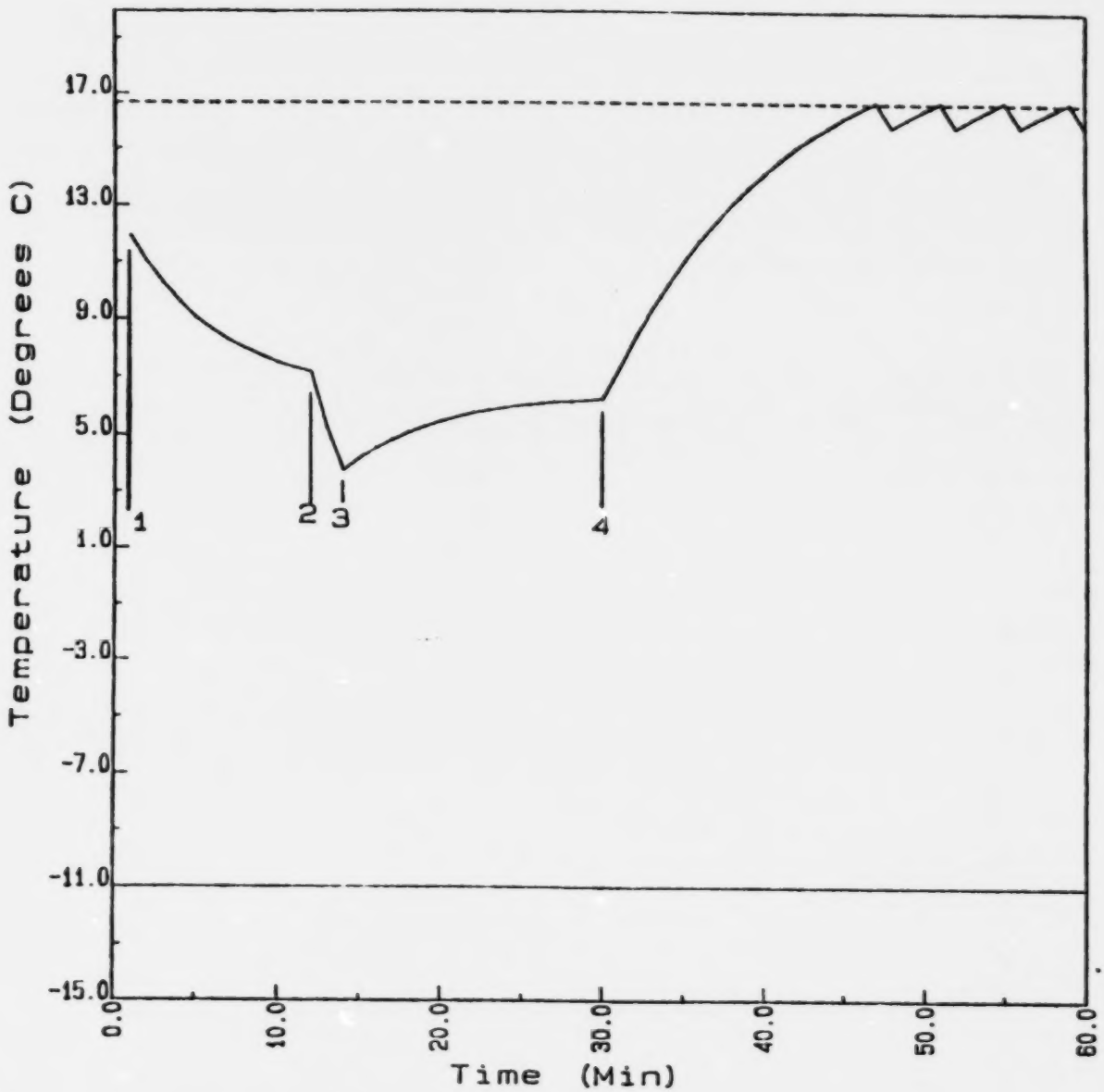


FIGURE 3

ORIENTATION PLAN OF STUDY AREA

APPROX. SCALE 1:1200



1- LONG CAR IN SHOP - SOUTH DOOR OPENS

2- NORTH DOOR OPENS

3- NORTH DOOR CLOSES

4- LONG CAR COMPLETED - SOUTH DOOR CLOSES

FIGURE 4(a)

INTERNAL TEMPERATURE VARIATION VS. TIME

FIRST HOUR

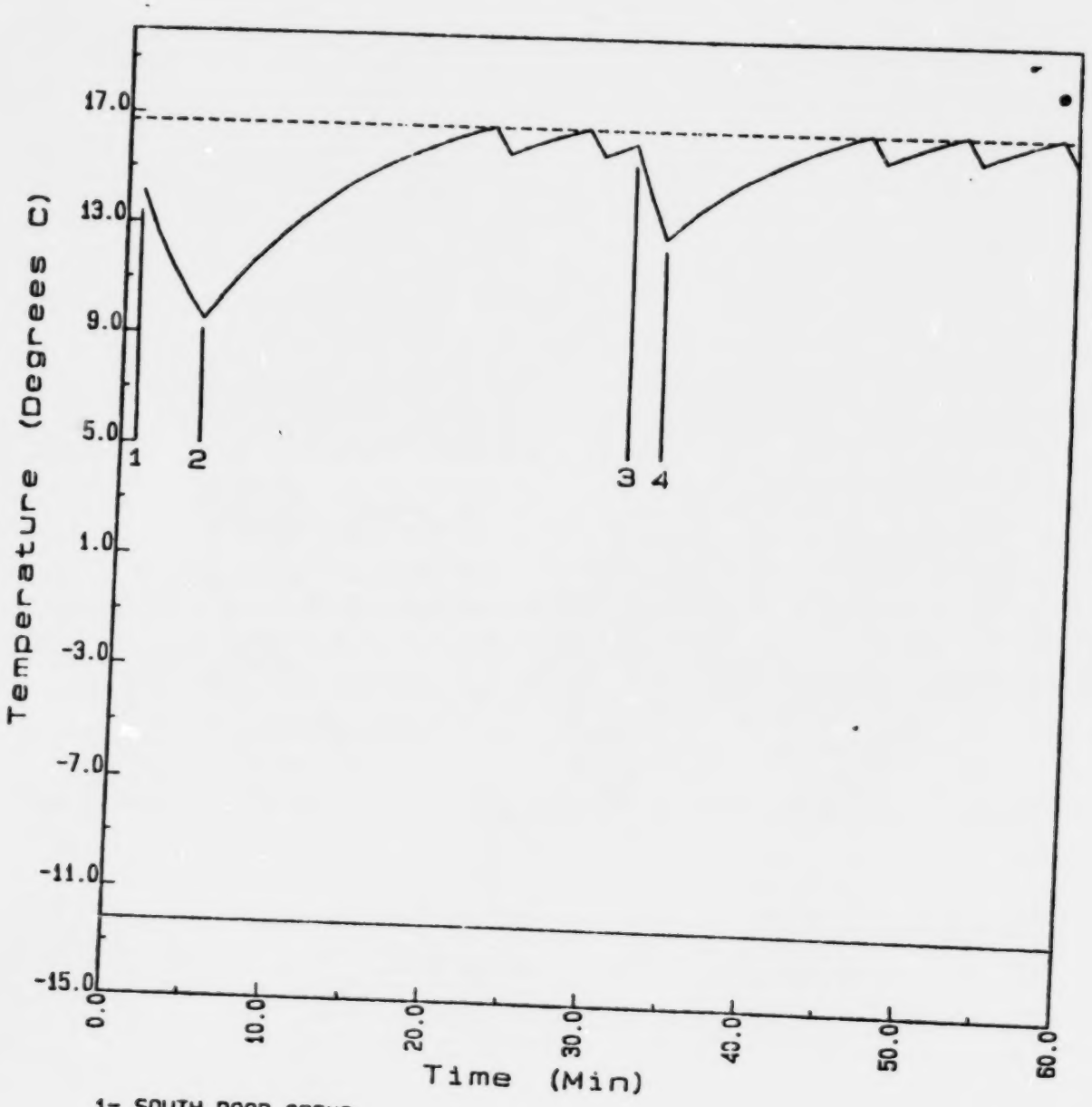
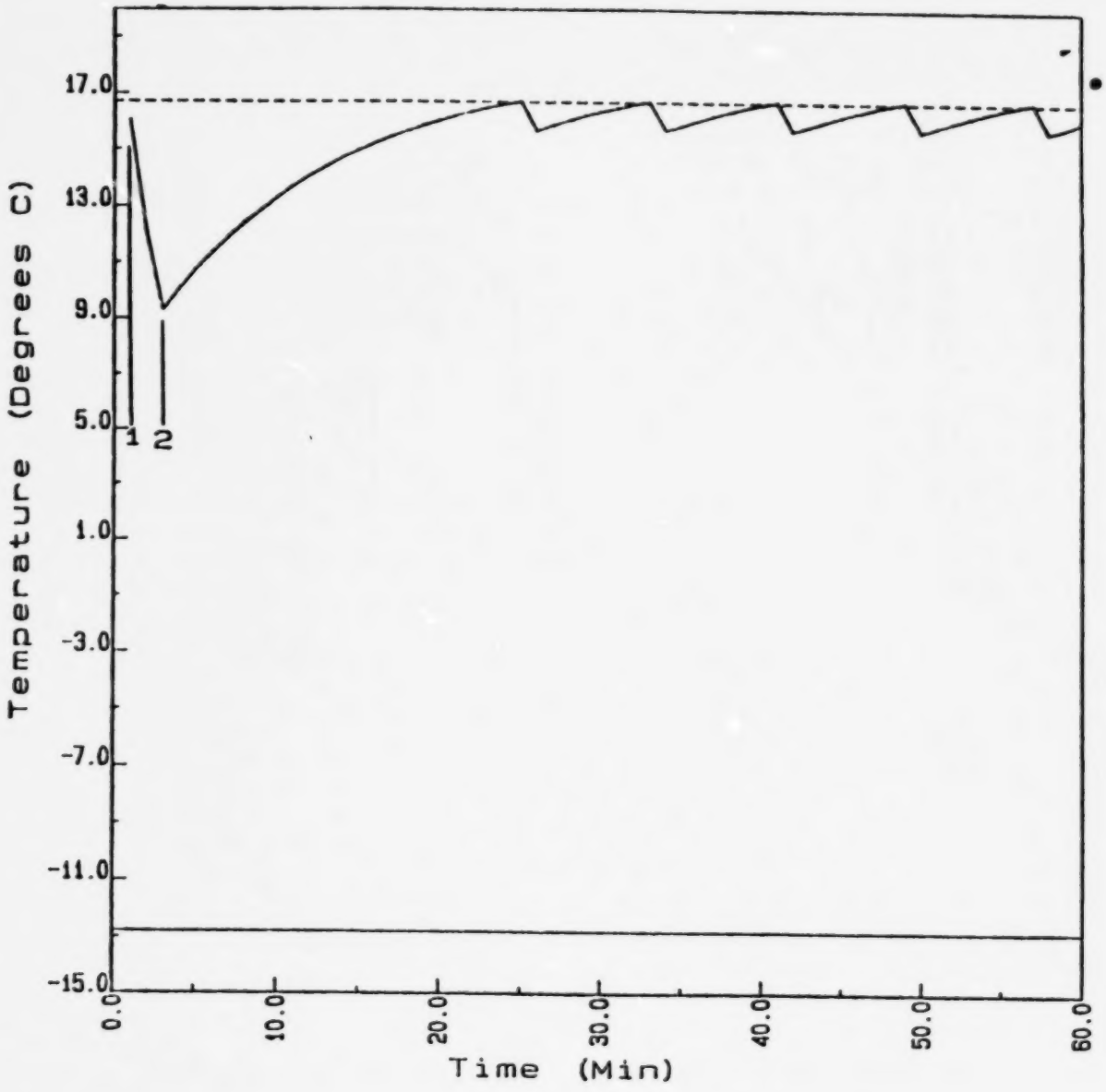


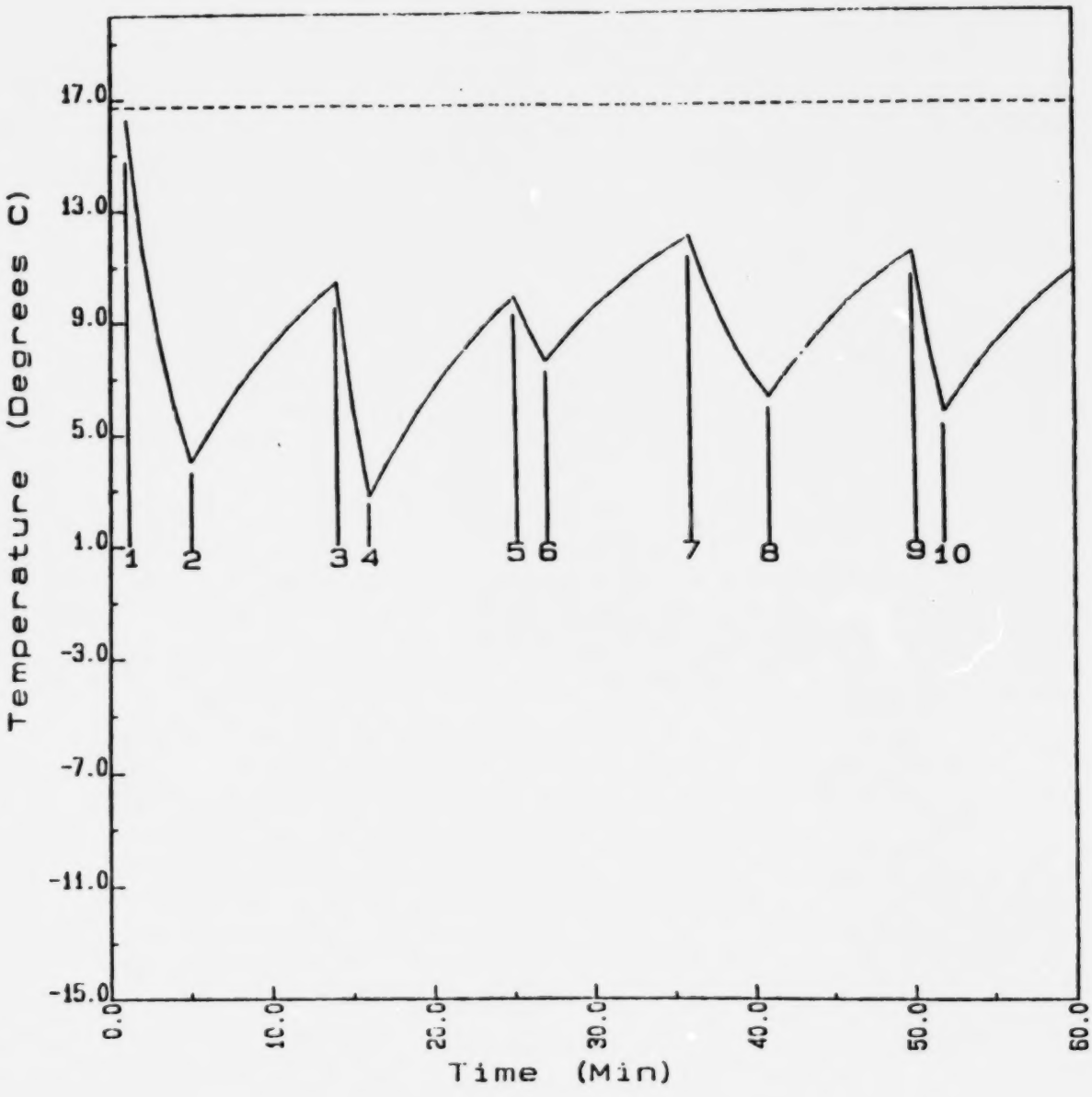
FIGURE 4 (b)
Internal Temperature Variation vs. Time
Second Hour



1- NORTH AND SOUTH DOOR OPEN

2- NORTH AND SOUTH DOORS CLOSE

FIGURE 4(c)
Internal Temperature Variation vs. Time
Third Hour



1- 2 DOORS ON ONE END OPEN

2- DOORS CLOSE

3- 2 DOORS ON ONE END, ONE ON THE OTHER OPEN

4- DOORS CLOSE

5- NORTH DOOR OPENS

6- DOOR CLOSES

7- SOUTH DOOR OPENS

8- DOOR CLOSES

9- NORTH AND SOUTH DOOR OPENS

10- DOORS CLOSE

FIGURE 4 (d)
Internal Temperature Variation vs. Time
Fourth Hour

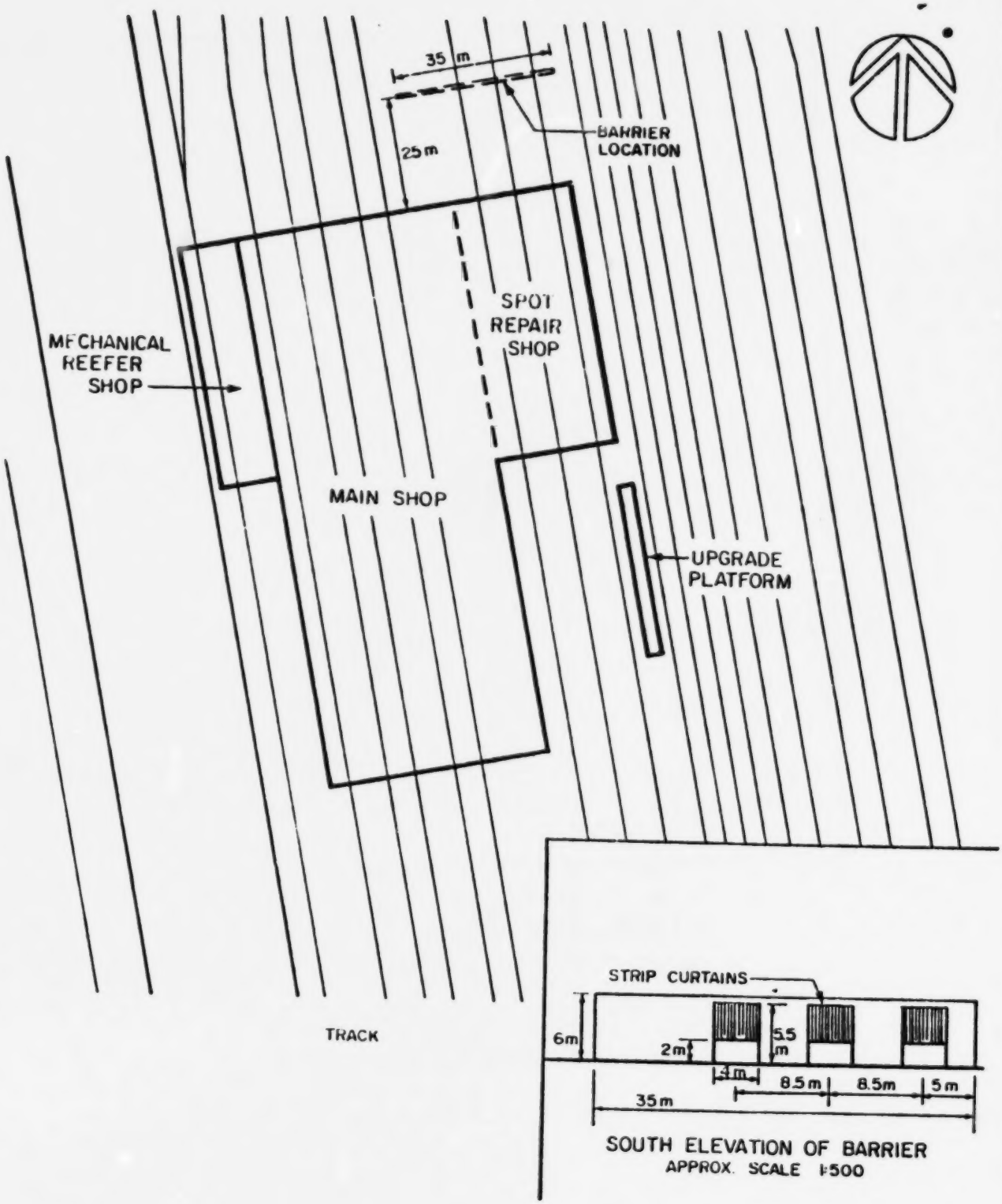
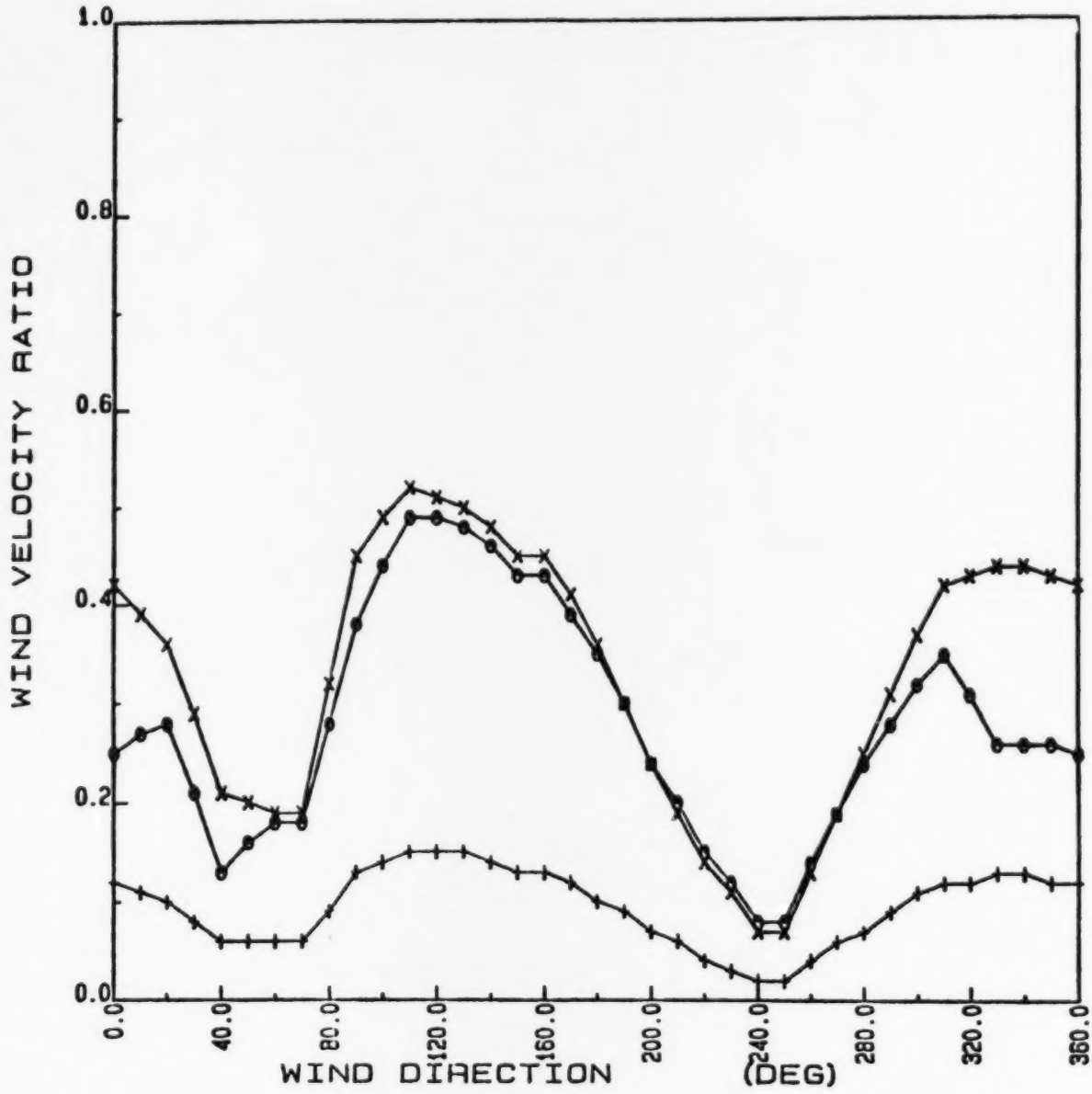


FIGURE 5
DETAILS OF WIND BARRIER
APPROX. SCALE 1:1200



× EXISTING CONDITION - NO MODIFICATIONS
⊙ WIND DEFLECTOR WALL IN PLACE
\+ STRIP CURTAINS IN SHOP DOORS - EFFECTIVE RATIO

FIGURE 6
Wind Velocity Ratios with One Door Open at Each End
V(doorway)/V(wind @ 10m elevation)

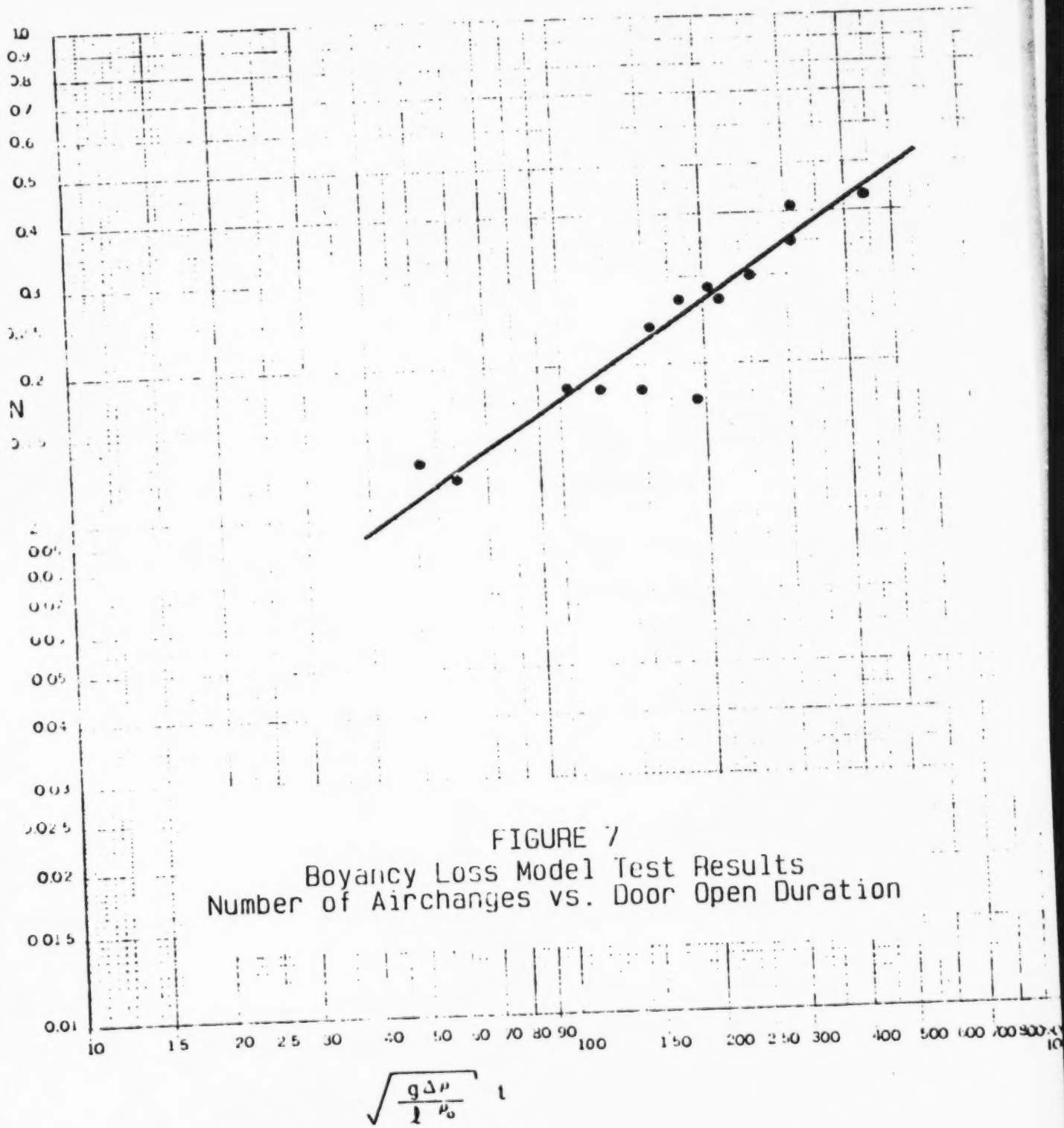


FIGURE 7
Boyancy Loss Model Test Results
Number of Airchanges vs. Door Open Duration

NORTH OPENS	NORTH CLOSES	SOUTH OPENS	SOUTH CLOSES
16:58	17:00	16:30	16:35
18:08	18:10	17:30	17:40
		18:08	18:12
19:30	19:32	19:36	19:40
20:03	20:05	20:13	20:20
20:50	20:52	20:53	21:00
22:00	22:02	21:18	21:21
		22:10	22:15
		22:40	22:47
22:45	22:47		

TABLE 1

EXAMPLE OF DOOR OPENING SURVEY
EVENING SHIFT, DECEMBER 8, 1982

OCCURRENCE	PROBABILITY %	DURATION MINUTES
1. 1 North Door Open Only	72.9	2
2. 1 South Door Open Only	72.9	5
3. 1 North and 1 South Door Open	37.5	2
4. 1 North and 2 South or 2 North and 1 South Open	20.8	2
5. 2 North and 2 South	4.1	2
6. 2 North or 2 South	20.8	3.5

TABLE 2

PROBABILITY AND DURATION OF DOOR OPEN OCCURRENCES

Case No.	Thermostat Mounting	Thermostat Setting °C	Remedial Solution	Heat Hours (Avg.)	Hours Below 6°C	Hours Below 0°Cz	% Reduction In Energy
1)	Existing	16.7	-	4550	184	41.3	-
2)	Existing	16.7	Wind Deflector	4544	171	38.2	0.1
3)	Existing	16.7	Strip Curtains	4324	34	1.2	5.0
*4)	Existing	16.7	Note: No wind losses	4507	128	26.4	0.9
*5)	Existing	16.7	Note: No buoyancy losses	4240	30	5.5	6.8
6)	Isolated	16.7	-	3470	186	43.7	23.7
7)	Isolated	16.7	Strip Curtains	3319	102	21.8	27.1
8)	Isolated	13	-	2701	202	42.6	40.6
9)	Isolated	13	Wind Deflector	2677	189	40.0	41.2
10)	Isolated	13	Strip Curtains	2552	106	22.6	43.9
11)	Isolated	13	Strip Curtains & Air Curtains on South Door - Unheated	2421	63	6.4	46.8
*12)	Isolated	13	Air Locks No Wind or Buoyancy Losses	2192	0	0	51.8

* Theoretical Cases

TABLE 3
RESULTS FROM COMPUTER SIMULATION

APPENDIX A

REDUCTION OF HEAT LOSS
SPOT REPAIR SHOP

A1.0 INVESTIGATION OF PRESENT HEATING SYSTEM

The present heating system for the spot repair shop is as follows:

1) 46 infrared heaters with input rating of 14.058 kW each - thermostat controlled

2) 2 makeup air heaters providing 4290 L/s of air each with an input rating of 311.2 kW

3) 4 exhaust fans remove air from the inside roof area with a rated capacity of 1902 L/s. Two are controlled by the infrared heater thermostats and two are manually controlled.

A1.1 Infrared Heaters

With the infrared heating system, heat energy is transferred by radiation to objects, people and floors warming them first and then by reradiation and convection to the surrounding objects and the air. After a door has been opened this direct radiation allows faster recovery to comfort conditions for personnel. It is therefore advised that, for this type of building, infrared heating is the most appropriate type.

A1.2 Heater Mounting

The existing infrared heaters are mounted 5.5 m from the floor in all areas except over the doors where the mounting height is 6.4 m. These distances are consistent with recommended practice for this size of unit. The units mounted along the walls containing track doors could be lowered 1 to 1.5 m but interference with rail cars would dictate careful location. The cost of relocation would not, in our opinion, be justified by improved conditions.

A1.3 Temperature Control

The terms of reference for operation of the Car Repair building showed a desired indoor space temperature of 13°C but investigation in the spot repair section found the thermostats set at 16.7°C.

The thermostats which control the infrared heaters along the exterior walls are mounted on exterior steel columns or on the walls and therefore do not truly sense the internal space temperature. Due to the high heat transmission rate of these members, the temperature sensed is close to that prevailing outside and therefore these heaters will run most of the time when the outside temperature is below 16.7°C during the heating season. These thermostats should either be disconnected and all heaters controlled by the centrally mounted thermostats or, as a minimum, be isolated from outside walls or columns by installing a 50.8 mm (2 inches) thick piece of polystyrene board behind each of them. The first alternative of rewiring these heater controls is preferable since it would eliminate the effects of the cold perimeter walls. All thermostats should be set to 13°C.

A1.4 Exhaust and Makeup Air

Two air makeup units, one at each end of the building, supply heated fresh air to replace that air removed by the exhaust fans. Exhaust air is necessary to remove the products of combustion from the unvented infrared heaters. Based on the total rated input to the heaters, two of the four fans only are required to provide sufficient exhaust. Since two are wired to the thermostats and start when the heaters start, the other two should be turned off in winter by the manual starter stations. Under this condition, the air makeup to the spot repair is 8580 L/s while the exhaust is 3800 L/s. With all outside doors closed and no wind pressure on the building, the interior should be under very slight positive pressure. This is certainly not conducive to poor comfort conditions and we recommend these capacities be left as they are. It was observed, however, that both air makeup units were inoperative. Both fans would function when the control was turned to the "Ventilation" mode but nothing operated in the "Heating" mode. It goes without saying that the controls should be repaired and the thermostats replaced or calibrated to make these units operational.

The personnel working in the spot repair area find these makeup units objectionable because they create cold air currents. This is, no doubt, due to the location of the air discharge openings; there is one over each track at a high level aimed almost horizontally at the track doors. The heated air being discharged mixes with the cold surrounding air and is diluted to such an extent that the effect at floor level is a cool breeze. It is recommended that these discharge ducts be extended to within 1 to 1.5 m of the door and then turned 90° so the warm air will be discharged downward, and possibly inward somewhat, to improve the effect at floor level.

A2.0 OPERATIONAL CONSIDERATIONS

The movement of cars into and out of the building required that doors be opened often. For safety reasons, these doors are interlocked with the robot car puller. The logistics of the car movement operation are proper and the track doors are open no more than required for the most part.

The lift truck door tended to remain open unnecessarily as material was retrieved from outside the building. The lift truck operator must dismount inside and outside the building to open and close the door. This he did not do when observed and the door remained open while he was outside. It is suggested that consideration be given to the use of an automatic opener controlled by a radio frequency transmitter on the lift truck. Manual door operation by the existing push buttons would continue to be available.

A3.0 REDUCTION OF FLOW THROUGH DOORWAYS

A3.1 Strip Curtains

To reduce the heat loss through open doors and reduce the cold wind effect inside the building, the addition of vinyl strip curtains to extend from the top of all track doors down to a point 2.1 m above the floor is recommended. The strips would be 3 mm thick by 305 mm wide and fully overlapped forming essentially a double thickness curtain. This configuration allows a clear line of sight at normal working height through the doorways with the overhead doors open. Safety considerations will be preserved and the curtains will offer minimum interference with the rail car movement through the doorway.

A3.2 Air Curtains

Air curtains, by themselves, have been examined as a possible solution. Computer simulations were done on the building and its operation taking into account the door opening schedules and Toronto weather data. The reduction in energy by the use of various air curtains on all doors and on south doors only is predicted by the computer. The following systems of air curtains were evaluated.

System 1 consists of air curtains mounted horizontally above each track door discharging 9270 L/s of air each. Directional control of the air stream is included based on wind pressure measured by a differential pressure sensor.

Estimated cost installed - unheated	- $54 600
Estimated cost installed - steam heated	- $78 800

System 2 consists of air curtains mounted horizontally above each track door discharging 11 750 L/s of air each. Directional control of the air stream is included.

Estimated cost installed - unheated	- $118 300
Estimated cost installed - steam heated	- $142 400

System 3 consists of air curtains mounted horizontally above the three south track doors discharging 11 750 L/s of air each. Directional control of the airstream is included.

Estimated cost installed - unheated	- $59 100
Estimated cost installed - steam heated	- $70 100

While the computer simulation of the above systems has an accuracy of only plus or minus 30% the results show that air curtains, by themselves, are not cost effective as illustrated below.

i) Savings using system 1 - air curtains on all six track doors = 223 850 kWh. At an infra-red heater conversion efficiency of 92% and a gas cost of $3.93/MCF for 1983, the savings are $3260.

ii) Savings using system 2 - air curtains on all six track doors = 241 720 kWh or $3520.

iii) Savings using system 3 - air curtains on south track doors only = 154 700 kWh or $2250.

As illustrated above, the use of air curtains above on the doors is not a cost effective solution. However, in the interest of improving comfort levels near the doorways, heated air curtains could be used in conjunction with strip curtains. On the three south doors only, heated, vertically mounted air curtains on each side of the door discharging 4530 L/s horizontally would be installed to protect only the lower 2.1 m. In this way, wind flows beneath the curtains would be reduced and the warm air discharge would have a positive effect on employee comfort and reaction.

Unheated air curtains are not recommended for this application because of the undesirable effect on employee comfort in the door vicinity.

A4.0 IMPLEMENTATION AND INITIAL COST

1) Pull the fuses or lock off the starters for two exhaust fans	No cost
2) Repair controls and calibrate thermostats for two air makeup units	$ 300
3) Extend and rework ducting on two air makeup units (six extensions)	$1800
4) Repair and calibrate thermostats for all infrared heaters. 14 @ $50 each	$ 700
5) Set all space thermostats to 13°C	No cost
6) Wire all perimeter heaters to centrally mounted thermostats 8 @ $300 each	$2400
7) Install vinyl strip curtains on six track doors - 12' 2" x 13' x 6 doors = 949 ft.^{2} @ $6.60/ft.^{2} = $6270 Installation $300/door x 6 = $1800	$8070
Subtotal	13 270
Contingency	1 330
Initial cost with no air curtains	14 600
8) Install air curtains on 3 south doors - one on each side of doorway	

6 @ $1775	$10650	
PST & Freight	1150	
Mech. installation		
6 @ $400	2400	
Elect. installation		
6 @ $850	5100	$19300
Subtotal		32570
Contingency		3260
Initial Cost With Unheated Air Curtains		$35830

Add for heated air curtains (390 000 BTU/hr each)

6 @ $795	$4 770	
PST	330	
Steam and condensate piping plus trap & valves	$4 550	9600
Subtotal		42170
Contingency		4230
Initial Cost With Heated Air Curtains		46400

A5.0 SAVINGS

a) Present gas consumption and 1983 cost for spot repair infra-red heaters - running hours from computer simulation -(Section 5.3 Table 3) - 4550

Gas consumption = 4550 hrs. x (46 heaters - 5% inoperative) x 48 000 BTU/hr. input each

= 9544 MCF or 270 240 m^3

1983 cost at $3.93/MCF $37 510

b) Revised gas consumption and 1983 cost for spot repair with 13°C thermostat setting, isolated perimeter thermostats and strip curtains; excluding air curtains - Running hours from computer simulation -2552 (Section 5.3, Table 3)
Gas consumption = 2552 x (46 -5%) x 48 000 BTU/hr. input each = 5353 MCF or 151 570 m^3

1983 cost at $3.93/MCF = $21 040

c) Revised gas consumption and 1983 cost with unheated air curtains. Reduction in heat required - from computer simulation - 240 MMBTU
Reduction in gas consumption at 92% efficiency of infra-red heaters = 240/0.92 = 261 MCF
Gas consumption = 5353 MCF-261 = 5092 MCF or 144 190 m^3

1983 cost at $3.93/MCF = $20 010

d) Additional electrical operating cost of air curtains (heated or unheated)
Open time for south track doors = 543 min/day
Alow 1 min. extra running time for each door closing 46 min/day

Air curtain running time 589 min/day

Electric power consumption =
1.5 HP/0.9 eff. x 0.95 util. x 0.746 kW/HP x (589 min/day)/(60 min/hr) x 200 days/yr = 2300 kWh/yr.

Additional cost of consumption at $0.0296/kWh = $70/yr

e) Additional natural gas cost for steam heated air curtains -

Heat which is added to the building by the air curtains displaces some heat which is normally supplied by the infra-red heaters and air makeup heaters. However, some of this heated air is lost to the outside because of outward air movement. In addition, the inside air temperature in the vicinity of the south doors will become more uniform but this will cause a higher energy consumption. Overall, we estimate that 25% of the heat input to the air curtains will be added consumption.

0.39 million BTU/hr per unit x 6 units x 0.25
x (589 min/day)/(60 min/hr) x 200 days/yr
= 1150 million BTU

Natural gas consumption at 75% steam system efficiency = 1150/0.75 = 1533 MCF or 43 420 m^3

Additional natural gas cost at \$3.93/MCF = \$6030/yr

f) Revised gas consumption and 1983 cost with heated air curtains

Consumption = 5092 MCF (from (c)) + 1533 MCF (from (e)) = 6625 MCF or 187 590 m^3

1983 cost = 6625 at \$3.93/MCF = \$26040/yr

g) Total energy cost savings with no air air curtains - including other recommendations

= \$37,510 (from (a)) - \$21,040 (from (b)) = \$16470/yr

h) Total energy cost savings with unheated air curtains

= \$37510 (from (a)) - \$20010 (from (c)) - \$70 (from (d)) = \$17430/yr

i) Total energy cost savings with heated air curtains
= $37510 (from (a)) - $26040 (from (f)) = $11400/yr

j) Additional annual maintenance cost - Replace 25% of vinyl strip curtains every three years ($949\ ft^2 \times 0.25 \times \$6.60/ft^2$) + ($100/door inst. x 6) = $2170

2170/3 = $725/yr
with no air curtains $725/yr

Repair to air curtains/cleaning - $300/yr

Total additional maintenance cost with air curtains = $1025/yr

A6.0 FINANCIAL ANALYSIS

Discounted cash flow analysis were prepared by computer for the present situation compared to three alternatives. These include all modifications: the first alternative using no air curtains; the second using unheated air curtains; and the third using heated air curtains.

The general inflation escalation used was 6% constant for 20 years and the discount rate was 25% constant for 20 years. The projected natural gas rates were provided by CN Rail for this analysis and Ontario Hydro provided their best estimate of 10% constant for 20 years for the electric power rate escalation. Comparisons were done between the discounted cash flows for the present situation and that for each of the alternatives. These are presented in Exhibits A1, 2 and 3. The summary of the results is contained in Exhibit A4.

Exhibit A1

**** UPW LIFE CYCLE COST COMPARISON ****

PROJECT : CAR REPAIR BUILDING - SPOT REPAIR AREA
COMMENTS : PRESENT HEATING SYSTEM - INFRA-RED ONLY

PROJECT : CAR REPAIR BUILDING - SPOT REPAIR AREA
COMMENTS : NO AIR CURTAINS

YEAR	(A) FILE 1 $	(B) FILE 2 $	(A-B) YR'S $	(A-B) CUM. $
1983	0.00	14600.00	-14600.00	-14600.00
1984	32297.60	18731.10	13566.50	-1033.50
1985	28098.90	16282.50	11816.40	10782.90
1986	24385.40	14120.30	10265.10	21048.00
1987	20641.70	11953.20	8688.50	29736.50
1988	17671.00	10229.90	7441.10	37177.60
1989	15437.40	8928.67	6500.73	43686.30
1990	13450.30	7773.10	5677.20	49363.50
1991	11576.90	6687.55	4889.35	54252.90
1992	10094.10	5826.37	4267.73	58520.60
1993	8864.27	5111.53	3752.74	62273.40
1994	7689.93	4431.63	3258.30	65531.70
1995	6775.14	3900.54	2874.60	69406.30
1996	5855.35	3369.38	2485.97	70892.20
1997	5150.36	2961.02	2189.34	73081.60
1998	4523.26	2598.30	1924.96	75006.50
1999	3916.78	2248.83	1667.95	76674.50
2000	3455.85	1982.41	1473.44	78147.90
2001	2986.41	1712.42	1274.00	79421.90
2002	2613.23	1497.42	1115.81	80537.70
2003	2299.64	1316.71	982.93	81520.70

*** APPARENT BREAK-EVEN YEAR = 1985 ***

Exhibit A2

**** UPW LIFE CYCLE COST COMPARISON ****

PROJECT : CAR REPAIR BUILDING - SPOT REPAIR AREA
COMMENTS : PRESENT HEATING SYSTEM - INFRA-RED ONLY

PROJECT : CAR REPAIR BUILDING - SPOT REPAIR AREA
COMMENTS : UNHEATED AIR CURTAINS

YEAR	(A) FILE 1 $	(B) FILE 2 $	(A-B) YR'S $	(A-B) CUM. $
1983	0.00	35830.00	-35830.00	-35830.00
1984	32297.60	18160.20	14137.40	-21692.60
1985	28098.90	15780.90	12318.00	-9374.60
1986	24385.40	13681.30	10704.10	1329.50
1987	20641.70	11583.50	9058.20	10387.70
1988	17671.00	9913.13	7757.87	18145.60
1989	15437.40	8648.84	6788.56	24934.10
1990	13450.30	7526.97	5923.33	30857.50
1991	11576.90	6475.06	5101.84	35959.30
1992	10094.10	5639.38	4454.72	40414.00
1993	8864.27	4945.31	3918.96	44333.00
1994	7689.93	4286.55	3403.38	47736.40
1995	6775.14	3771.08	3004.06	50740.40
1996	5855.35	3257.06	2598.29	53338.70
1997	5150.36	2861.11	2289.25	55628.00
1998	4523.26	2509.68	2013.58	57641.60
1999	3916.70	2171.78	1745.00	59386.60
2000	3455.85	1913.67	1542.10	60928.70
2001	2986.41	1652.84	1333.57	62262.30
2002	2613.23	1444.91	1168.32	63430.60
2003	2299.64	1270.09	1029.55	64460.20

*** APPARENT BREAK-EVEN YEAR = 1986 ***

Exhibit A3

**** UPW LIFE CYCLE COST COMPARISON ****

PROJECT : CAR REPAIR BUILDING - SPOT REPAIR AREA
COMMENTS : PRESENT HEATING SYSTEM - INFRA-RED ONLY

PROJECT : CAR REPAIR BUILDING - SPOT REPAIR AREA
COMMENTS : HEATED AIR CURTAINS

YEAR	(A) FILE 1 $	(B) FILE 2 $	(A-B) YR'S $	(A-B) CUM. $
1983	0.00	46400.00	-46400.00	-46400.00
1984	32297.60	23352.30	8945.30	-37454.70
1985	28098.90	20298.00	7800.90	-29653.80
1986	24385.40	17601.40	6784.00	-22869.80
1987	20641.70	14901.80	5739.90	-17129.90
1988	17671.00	12753.90	4917.10	-12212.80
1989	15437.40	11130.50	4306.90	-7905.91
1990	13450.30	9689.20	3761.10	-4144.80
1991	11576.90	8336.13	3240.77	-904.80
1992	10094.10	7262.08	2832.02	1927.99
1993	8864.27	6370.30	2493.97	4421.96
1994	7689.93	5522.76	2167.17	6589.13
1995	6775.14	4860.23	1914.91	8504.04
1996	5855.35	4198.34	1657.01	10161.00
1997	5150.36	3689.07	1461.29	11622.30
1998	4523.26	3236.83	1286.43	12908.80
1999	3916.78	2801.43	1115.35	14024.10
2000	3455.85	2469.22	986.63	15010.70
2001	2986.41	2132.92	853.49	15864.20
2002	2613.23	1865.00	748.23	16612.50
2003	2299.64	1639.77	659.87	17272.30

*** APPARENT BREAK-EVEN YEAR = 1992 ***

EXHIBIT A4

FINANCIAL ANALYSIS SUMMARY

	System Without Air Curtains	System With Unheated Air Curtains	System Including Heated Air Curtains
Initial Investment	14 600	35 830	46 400
1983 Gas Cost - Present System	37 510	37 510	37 510
1983 Gas Cost - New System	21 040	20 010	26 040
1983 Gas Cost Saving	16 470	17 500	11 470
1983 Additional Electric Cost - New System	0	70	70
1983 Net Energy Cost Saving	16 470	17 430	11 400
1983 Additional Maintenance Cost	725	1 025	1 025
1983 Net Operating Saving	15 745	16 405	10 375
Simple Payback	0.93 yrs.	2.18 yrs.	4.5 yrs.
Net Present Value	81 521	64 460	17 272
True Payback	1.1 yrs.	2.9 yrs.	8.3 yrs.